Why We Study Single Stars with Interferometry

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A.A. Michelson, 1903

“The investigation of the size and structure of the heavenly bodies is limited by the resolving power of the observing telescope. When the bodies are so small that this limit of resolution is passed, the telescope can give no information concerning them. But an observation of the visibility curves of the interference fringes due to such sources, when made by the method of the double slit or its equivalent, and properly interpreted, gives information concerning the size, shape and distribution of the components of the system. Even in the case of a fixed star, which may subtend an angle of less than one-hundredth of a second, it may not be an entirely hopeless task to attempt to measure its diameter by this means”

A.S. Eddington, 1920

“Perhaps the greatest need of stellar astronomy at the present day, in order to make sure that our theoretical deductions are starting on the right lines, is some means of measuring the apparent angular diameters of stars”

A.A. Michelson & F.G. Pease, 1921

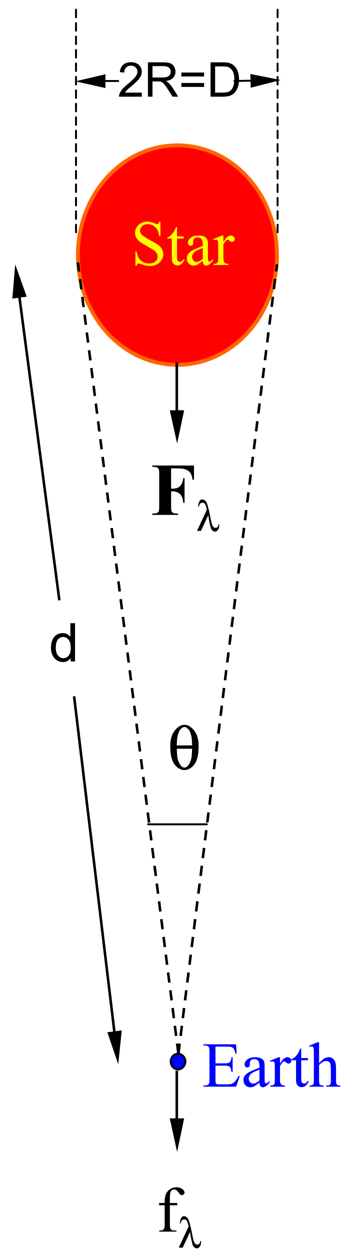
“Measurement of the Diameter of α Orionis with the Interferometer”

Angular diameter equal to 0.047 arc seconds for a uniformly illuminated disk with an uncertainty of $\sim 10\%$.

Bread and Butter!

The measurement of Angular Diameters leading to the determination of fundamental stellar properties:

- Emergent Fluxes
- Effective Temperatures
- Radii &
- Luminosities



Angular diameter plus flux data:

$$4\pi R^2 \mathbf{F}_\lambda = 4\pi d^2 f_\lambda$$

$$\therefore \quad \mathbf{F}_\lambda = \frac{4}{\theta^2} . f_\lambda$$

Emergent Flux

$$\int_0^\infty \mathbf{F}_\lambda . d\lambda = \int_0^\infty \frac{4}{\theta^2} . f_\lambda . d\lambda = \sigma T_e^4$$

Effective Temperature

If the distance is known:

$$2R = D = d\,\theta$$

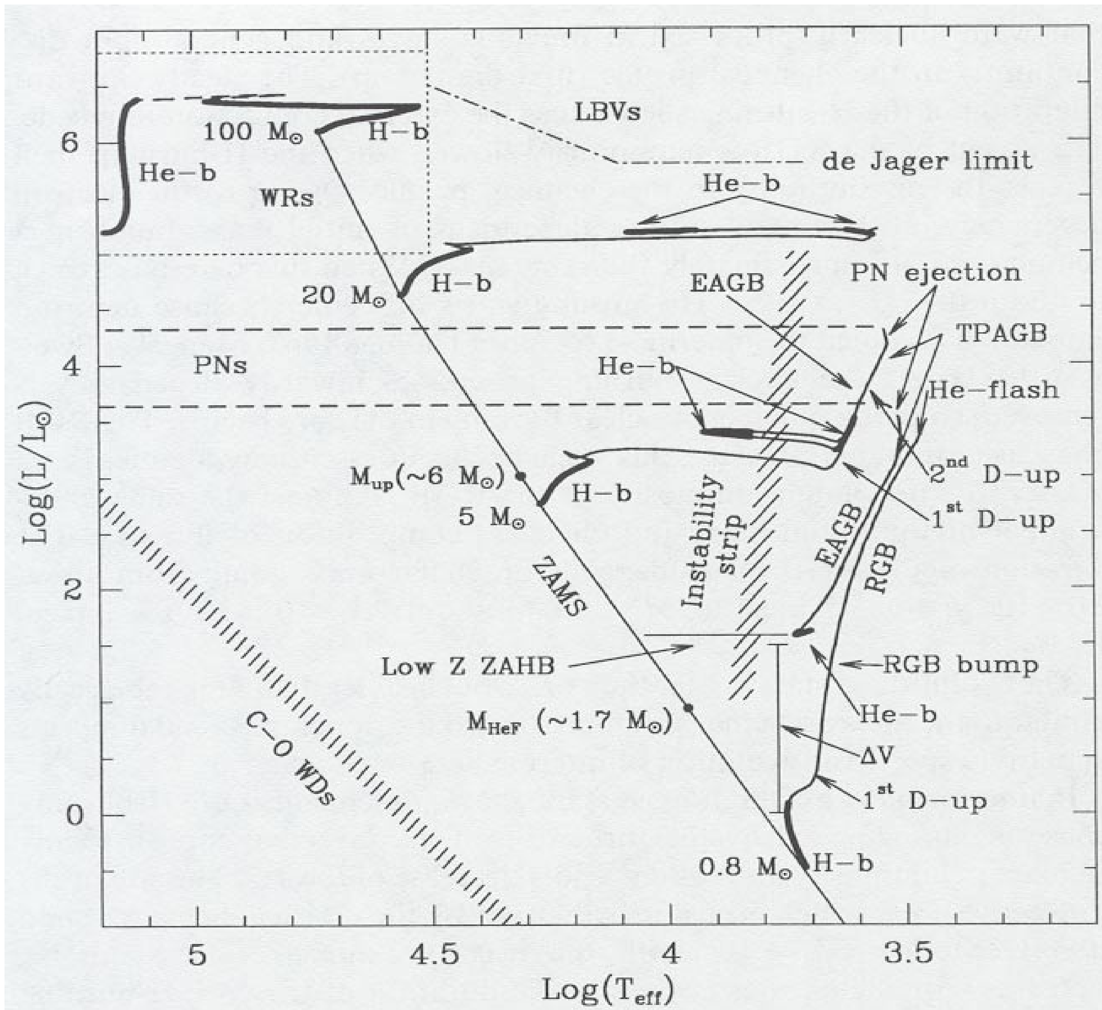
Radius

and $$L = 4\pi R^2 \sigma T_e^4$$

Luminosity

Theoretical HR Diagram

(Chiosi et al., Ann.Rev.Astron.Astrophys., 30, pp.235-285, 1992)



A Bit of Theory

The complex visibility V_b and the angular distribution of intensity across a source I_α are a Fourier transform pair:

$$V_b \xleftrightarrow{FT} I_\alpha$$

where $$V_b = |V_b| \exp(i\phi_b)$$

In principle, measurement of $|V_b|$ and ϕ_b over an appropriate range of baseline lengths and orientations ((u,v) plane cover) would enable an image of the source to be constructed.

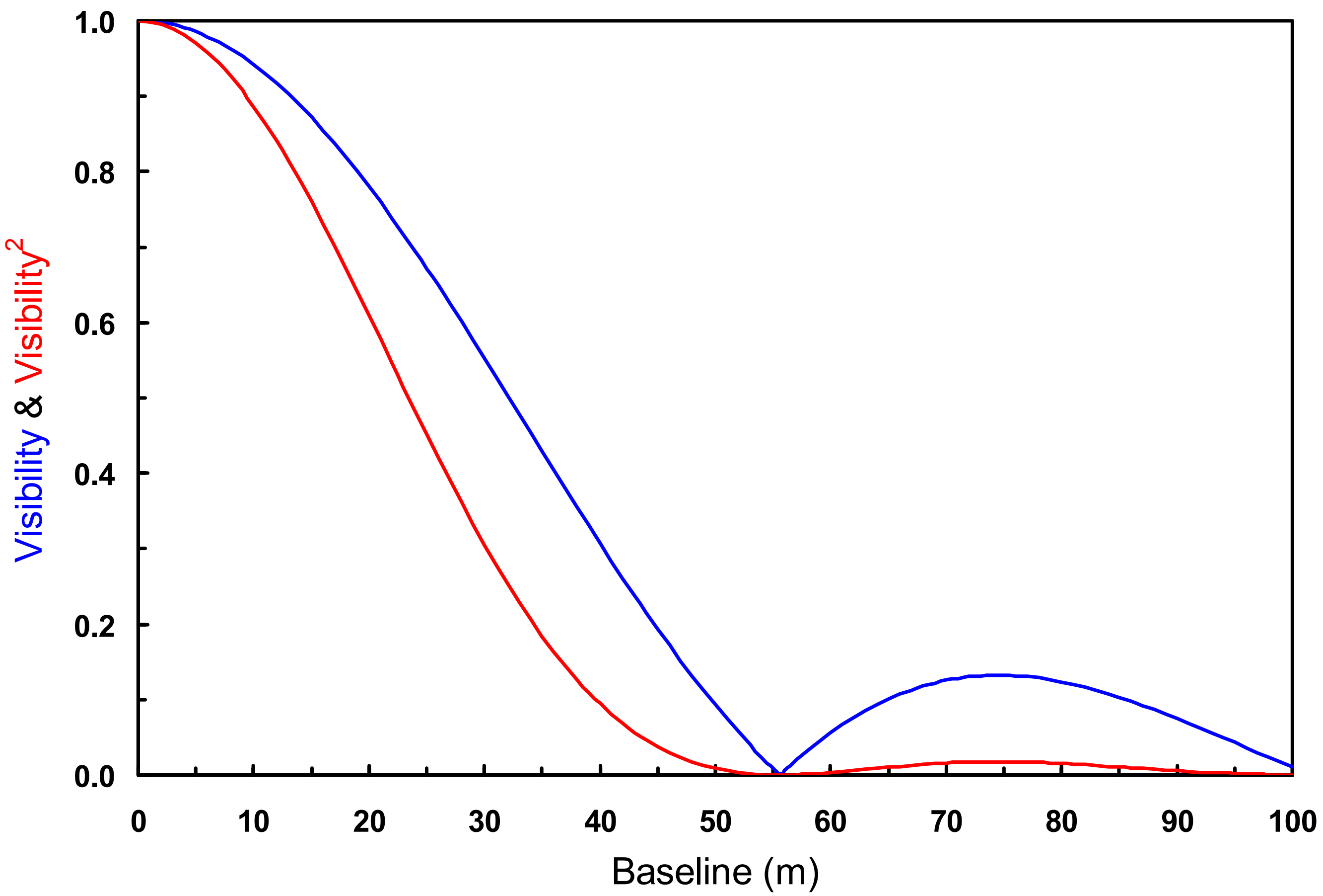
So far, most interferometric measurements of stellar angular diameters have been made with measurements of $|V_b|^2$.

These measurements are generally fitted with the relationship for a uniformly illuminated disk:

$$|V_b|^2 = |2J_1(x)/x|^2 \quad \text{where} \quad x = \pi b\theta/\lambda$$

Visibility v. Baseline for a Uniformly Illuminated Disk

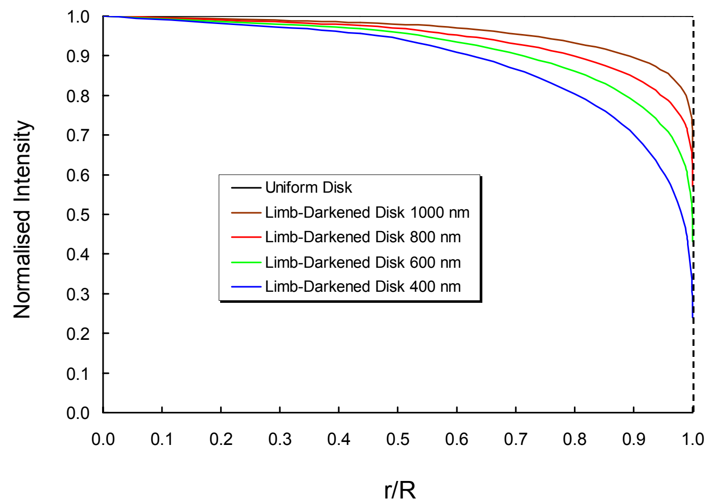
(Angular Diameter = 2.0 mas: Wavelength = 442 nm)



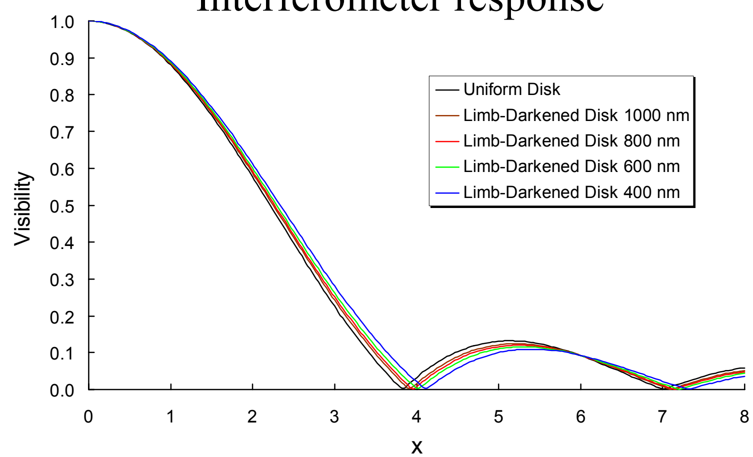
Limb-Darkened Stellar Disks

Kurucz model atmosphere for Te = 10000K and log g = 4.0

Centre-to limb intensity variation

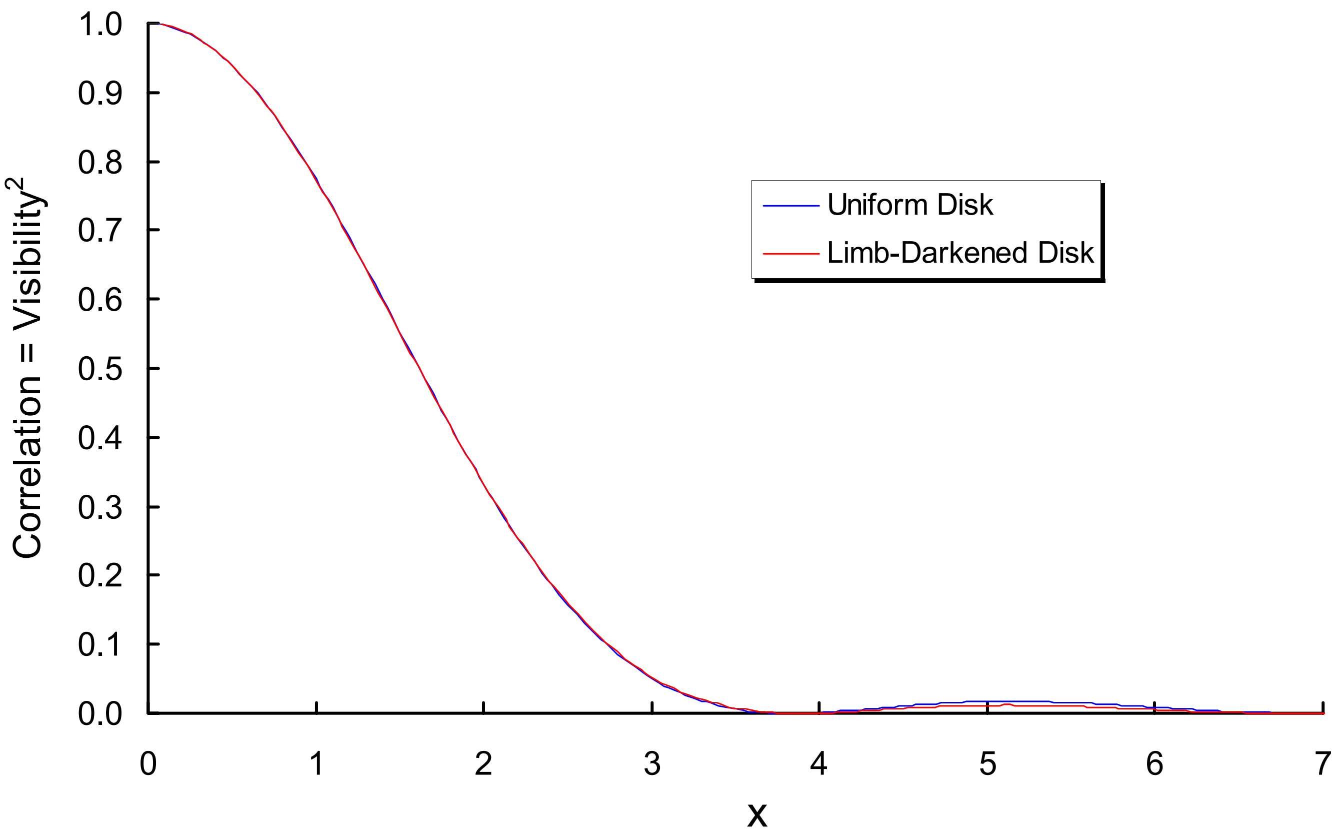


Interferometer response



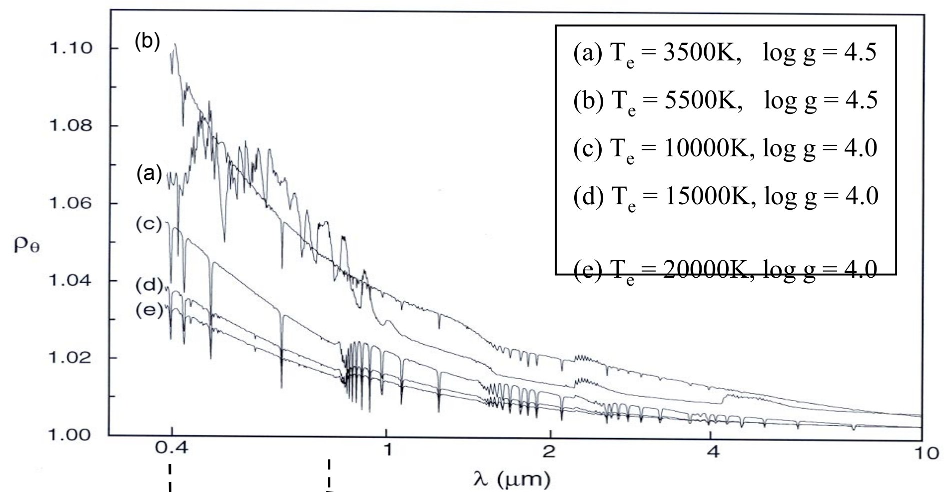
Comparison of Uniform Disk and Limb-Darkened Disk Responses

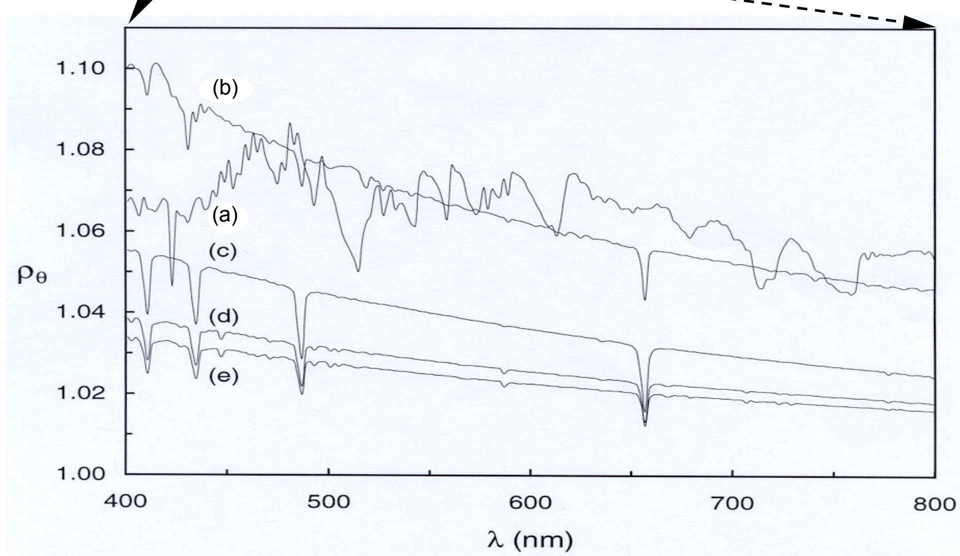
Curves matched at correlation = 0.3   (θ_{LD}/θ_{UD} = 1.055)



$\rho_\theta = \theta_{LD}/\theta/_{UD}$ for Kurucz Model Atmospheres

(Ref: Davis, Tango & Booth, MNRAS, 2000)

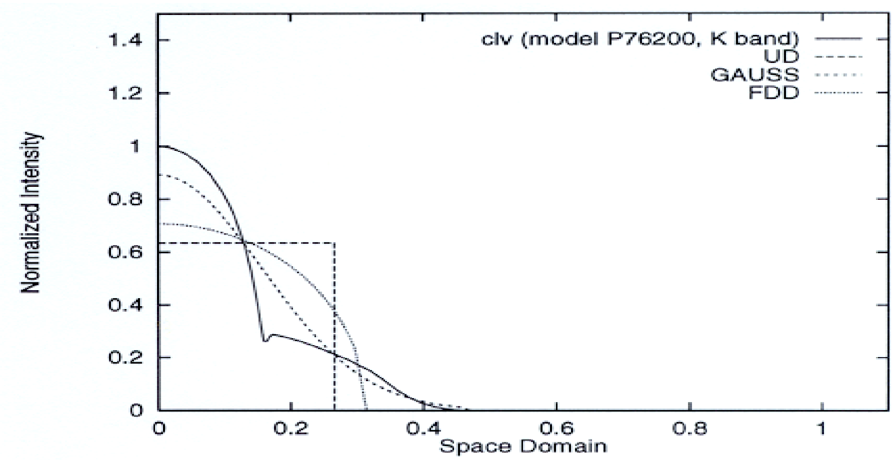




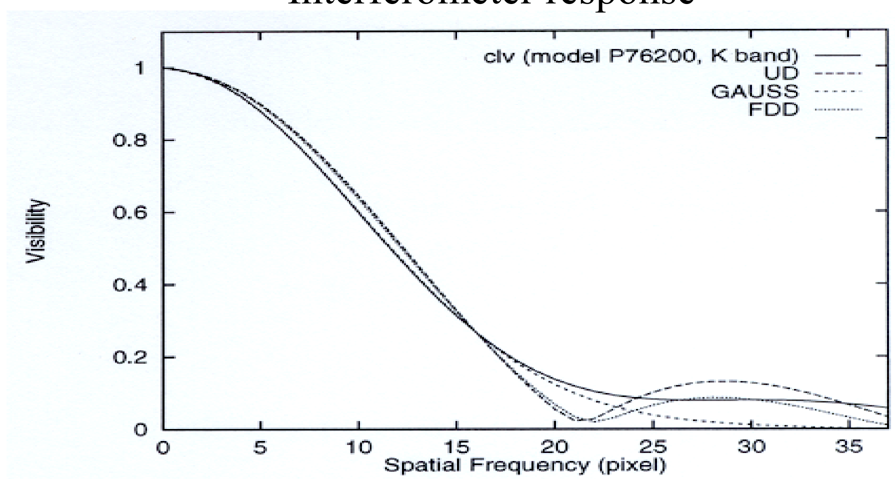
Limb-Darkening for M-type Mira Models

(Ref: Hofmann, Scholz & Wood, A&A, 339, 846, 1998)

Centre-to-limb intensity variation



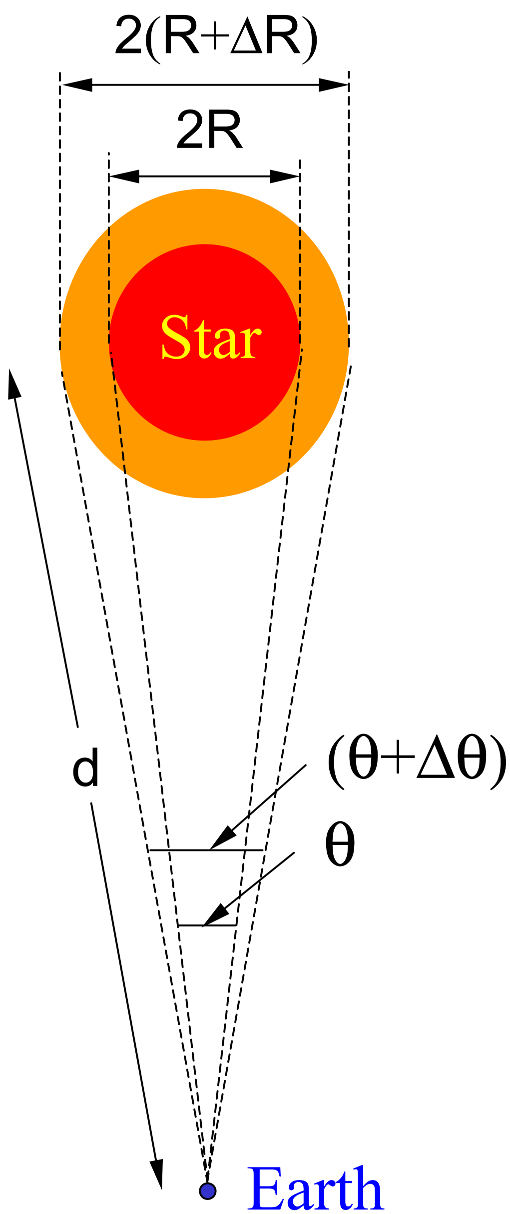
Interferometer response



A Whole Lot More!

Examples include:

- Pulsating stars - e.g. Cepheids, Miras
- Rotation - absolute, distortion
- Pre-main sequence objects
- Young stars - structure and morphology
- Extended corona
- Hot star emission envelopes, shells, winds etc.
- Cool star circumstellar dust shells
- Novae/Supernovae
- Images - stellar surface features plus several of the above items
- etc.



Pulsating Stars

Emergent flux F_λ and effective temperature T_e as for non-pulsating stars

Distance: $d = 2\,\Delta R/\Delta\theta$

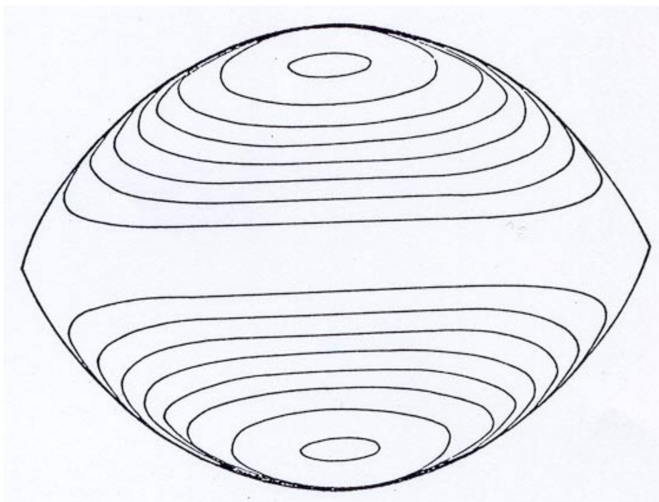
With distance determined (or known) we can establish radius R and luminosity L

Complementary Data Required

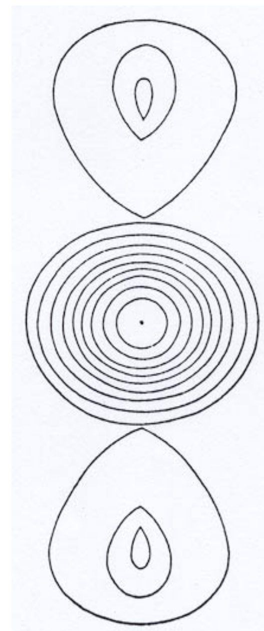
1. For Effective Temperatures	Absolute flux distributions	Visual spectrophotometry Narrow band photometry UV and IR fluxes
	Limb darkening	Model atmospheres
2. For Radii and Luminosities	Distances	Astrometry (e.g. Hipparcos data)
	Effective temperatures	From Item (1)
3. For Distances, Effective Temperatures, Radii & Luminosities of Pulsating Stars	Absolute flux distributions	As for Item (1)
	Change in Radius	High resolution spectroscopy
	Limb darkening & separation of continuum and line forming regions	Model atmospheres

Rapidly Rotating Stars

The model used for this illustration was generated for the Narrabri Stellar Intensity Interferometer programme by P. Strittmatter

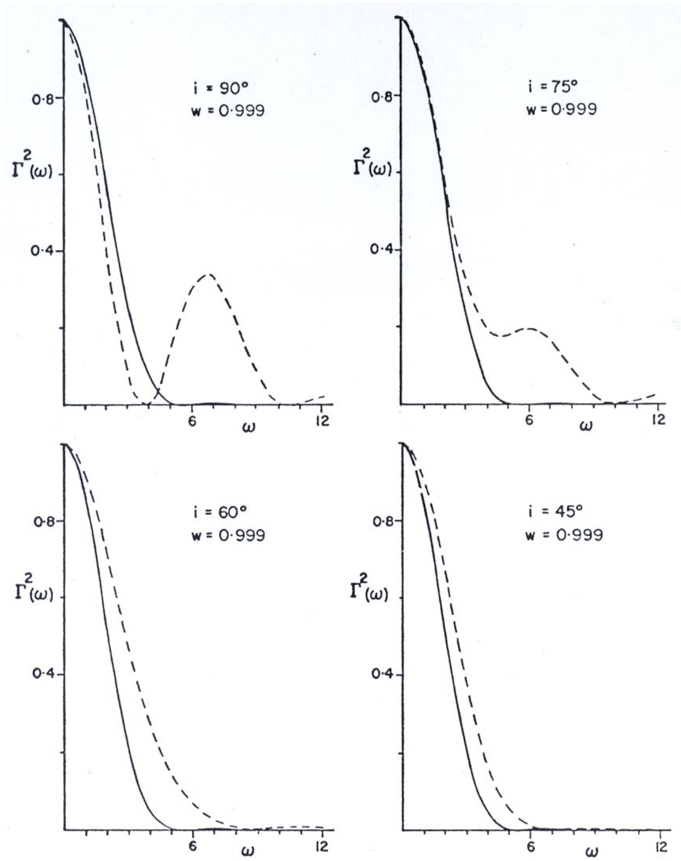


Projected brightness distribution for a star of spectral type A7 rotating at the critical velocity and seen equator-on at a wavelength of 443 nm.



The central region of the $(\text{visibility})^2$ function corresponding to the brightness distribution shown on the left.

Interferometric Responses to a Rapidly Rotating Star



Cross-sections of the (visibility)^2 function for the model shown in the previous slide for the axis of rotation at different inclination angles. Note that $\Gamma^2(\omega)$ = (visibility)^2. The solid lines are for cross-sections perpendicular to the projected axis of rotation and the dashed curves are for cross-sections parallel to the projected axis of rotation.

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